WHAT IS CLAIMED:

1. A method of characterizing defects in a part, the method comprising:

a) identifying a numerically quantifiable physical property that provides good part array A_i of n numerical values given by equation 1 that characterize a first reference part without a defect and defect array B_i of n values as provided by equation 2 that characterize a second reference part with a known defect:

$$A_i \in (A_1, A_2, \ldots A_n) \qquad 1;$$

$$B_i \in (B_1, B_2, \ldots B_n) \qquad 2;$$

wherein,

n is an integer, and

array A_i and array B_i are ordered by an independent parameter p_i that is associated with the values in array A_i and array B_i through the functional relationship $A_i = f_a(p_i)$ and $B_i = f_b(p_i)$;

b) creating good part vector **A** of n dimensions as provided by equation 3 whose components are the n numerical values in good part array A_i:

$$\mathbf{A} = \langle A_1, A_2, \ldots A_n \rangle \qquad 3;$$

c) creating defect vector **B** of n dimensions as provided by equation 4 whose components are the n values in defect array B_i:

$$\mathbf{B} = \langle B_1, B_2, \ldots B_n \rangle \qquad 4;$$

d) identifying vector **R** by selecting a vector from the group consisting of vector **B**, vector **C**, vector **D**, and vector **E**;

wherein,

vector **C** is created by taking the difference between good part vector **A** and defect vector **B** as provided in equation 5:

$\mathbf{C} = \mathbf{A} - \mathbf{B}$ 5; and

vector **D** is formed by:

1) creating difference vector **C** of n dimensions as provided by equation 5 which is the difference between good part vector **A** and defect vector **B**:

$\mathbf{C} = \mathbf{A} - \mathbf{B}$ 5;

2) identifying m components of vector **C** as provided by equation 6 having the largest magnitudes:

$C'_i \in (C'_1, C'_2, \ldots C'_m)$ 6;

3) creating vector **D** of m dimensions as provided by equation 7 whose components are the n values in array C'_i

$\mathbf{D} = \langle C'_1, C'_2, \ldots C'_m\rangle$
$= \langle D_1, D_2, \ldots D_m\rangle$ 7;

and

vector **E** is formed by:

1) creating difference vector **C** of n dimensions as provided by equation 5 which is the difference between good part vector **A** and defect vector **B**:

$\mathbf{C} = \mathbf{A} - \mathbf{B}$ 5;

2) identifying m components of vector **C** as provided by equation 6 having the largest magnitudes:

$C'_i \in (C'_1, C'_2, \ldots C'_m)$ 6;

3) creating vector **D** of m dimensions as provided by equation 7 whose

components are the n values in array C'_i

$$\mathbf{D} = \langle C'_1,\ C'_2,\ \ldots\ C'_m \rangle = \langle D_1,\ D_2,\ \ldots\ D_m \rangle \qquad 7;$$ and

5) normalizing vector **D** to form vector **E** as provided in equation 9:

$$\mathbf{E} = \mathbf{D}/|\mathbf{D}| \qquad 8;$$

e) determining array F_i of n numerical values as provided by equation 9 that characterize a test part that may have an unknown defect using the numerically quantifiable physical property:

$$F_i \in (F_1,\ F_2,\ \ldots\ F_n) \qquad 9;$$

f) creating vector **F** of n dimensions as provided by equation 10 whose components are the n values in array F_i:

$$\mathbf{F} = \langle F_1,\ F_2,\ \ldots\ F_n \rangle \qquad 10;$$

g) identifying vector **S** by selecting a vector selected from the group consisting of vector **F**, vector **G**, vector **H**, and vector **I**,

wherein,

vector **G** is formed by taking the difference between vector **A** and vector **F** as provided in equation 11;

$$\mathbf{G} = \mathbf{A} - \mathbf{F} \qquad 11;$$ and

vector **H** is formed by:

1) creating vector **G** as provided by equation 11 which is the difference between vector **A** and vector **F**:

$$\mathbf{G} = \mathbf{A} - \mathbf{F} \qquad 11;$$

2) identifying m components of vector **G** as provided by equation 12 which correspond to the same values for p_i as

the m components selected in step d for vector **F**:

$$G'_i \in (G'_1, G'_2, \ldots G'_m) \quad 12;$$

3) creating vector **H** as provided in equation 13 of dimension m having as components only the m components of step 2:

$$\mathbf{H} = \langle G'_1, G'_2, \ldots G'_m \rangle = \langle H_1, H_2, \ldots H_m \rangle \quad 13;$$

4) normalizing vector **H** to create vector **I** as provided in equation 14:

$$\mathbf{I} = \mathbf{H}/|\mathbf{H}| \quad 14;$$ and

vector **I** is formed by:

1) creating vector **G** as provided by equation 11 which is the difference between vector **A** and vector **F**:

$$\mathbf{G} = \mathbf{A} - \mathbf{F} \quad 11;$$

2) identifying m components of vector **G** as provided by equation 12 which correspond to the same values for p_i as the m components selected in step d for vector **F**:

$$G'_i \in (G'_1, G'_2, \ldots G'_m) \quad 12;$$

3) creating vector **H** as provided in equation 13 of dimension m having as components only the m components of step 2:

$$\mathbf{H} = \langle G'_1, G'_2, \ldots G'_m \rangle = \langle H_1, H_2, \ldots H_m \rangle \quad 13;$$

4) normalizing vector **H** to create vector **I** as provided in equation 14:

$$\mathbf{I} = \mathbf{H}/|\mathbf{H}| \quad 14;$$ and

h) forming dot product DP as provided in equation 15:

$$DP = \mathbf{R} \bullet \mathbf{S} \qquad 15;$$

wherein the dot product provides a number related to the probability that the test part that may have an unknown defect has the known defect in the second reference part with the proviso that when

vector **B** is selected in step d vector **F** is selected in step g,

vector **C** is selected in step d vector **G** is selected in step g,

vector **D** is selected in step d vector **H** is selected in step g, and

vector **E** is selected in step d vector **I** is selected in step g.

2. The method of claim 1 wherein m is less than n.

3. The method of claim 1 wherein the dot product P is provided by DP = $\mathbf{E} \bullet \mathbf{I}$.

4. The method of claim 1 wherein each of the normalization steps is performed by dividing a vector component of a vector to be normalized by the magnitude of the vector, the magnitude given by the square root of the sums of the squares of the vector components.

5. The method of claim 1 wherein the numerical physical property is a frequency spectrum which is the vibrational magnitude at one or more positions on the part as a function of frequency.

6. The method of claim 5 wherein

good part array A_i, defect array B_i, and array F_i are each ordered by n frequencies;

the n numerical values in good part array A_i are magnitudes from the frequency spectrum of the first reference part without a defect at each of the n frequencies;

the n numerical values in defect array B_i are magnitudes from the frequency spectrum of the second reference part with a known defect at each of the n frequencies; and

the n numerical values in array F_i are magnitudes from the frequency spectrum of a test part that may have an unknown defect at each of the n frequencies.

7. The method of claim 6 wherein the frequency spectrum of the first reference part, the second reference part, and the test part are determined by:

independently subjecting each of the first reference part, the second reference part, and the test part to energy that is sufficient to excite vibrational modes in each part;

independently measuring the magnitude of vibrations at one or more positions on each as a function of time to form a time domain spectra that is a plot of the magnitude of the vibrational energy as a function of time; and

independently creating a frequency domain spectra for each part by taking the Fourier transform of the time domain spectra.

8. The method of claim 7 wherein the part is a component of a vehicle powertrain and the subjecting a part

to energy that is sufficient to excite vibrational modes in a part comprises:

operating the part in a manner as the part would be operated during operation of the powertrain.

9. The method of claim 7 further comprising:

calculating for each n frequencies a corresponding order;

reexpressing the frequency spectrum as a rotational order spectrum which is a plot of the vibration magnitude as a function of rotational order; wherein

the good part array A_i, defect array B_i, and array F_i are each ordered by the n rotational orders;

the n numerical values in good part array A_i are magnitudes from the rotational order spectrum of the first reference part without a defect at each of the n orders;

the n numerical values in defect array B_i are magnitudes from the rotational order spectrum of the second reference part with the known defect at each of the n orders; and

the n numerical values in array F_i are magnitudes from the order spectrum of the test part that may have an unknown defect at each of the n orders.

10. The method of claim 9 wherein the order is determined by dividing a frequency in the frequency spectrum by a reference frequency.

11. The method of claim 9 wherein the reference frequency is an input rotational frequency or output rotational frequency.

12. The method of claim 9 wherein the rotational frequency is determined of the rotation of a shaft within the part.

13. The method of claim 1 wherein steps a through o for each member of a set parts each with a known defects wherein the defect vector **B** is created for each member of the set.

14. A method of characterizing defects in a part, the method comprising:

a) providing a first collection of reference parts wherein each part in the set has a known defect;

b) identifying a numerically quantifiable physical property that provides good part array A_i of n values given in equation 1 that characterizes a part without a defect and provides a collection $B^j{}_i$ of arrays given by equation 17 that characterize each part in the collection of reference parts, each member of the second collection of arrays corresponds to one member of the collection of reference parts and has n dimensions:

$$A_i \in (A_1,\ A_2,\ .\ .\ .\ A_n) \qquad 1;$$

$$B^j{}_i \in (B^j{}_1,\ B^j{}_2,\ .\ .\ .\ B^j{}_n) \qquad 16;$$

wherein,

n is an integer, and

array A_i and array $B^j{}_i$ are ordered by the same independent parameter p_i that is associated with the values in array A_i and array $B^j{}_i$ through the functional relationship $A_i = f_a(p_i)$ and $B^j{}_i = f^j{}_b(p_i)$;

c) creating good part vector **A** of n dimensions given by equation 3 whose components are the n numerical values in good part array A_i

$$\mathbf{A} = \langle A_1,\ A_2,\ .\ .\ .\ A_n \rangle \qquad 3;$$

d) creating collection $\mathbf{B}^j$ of defect vectors of n dimensions as given in equation 17, the components of each defect vector in the third collection being the n numerical values of each array in the second collection of arrays;

$$\mathbf{B}^j = \langle B^j{}_1,\ B^j{}_2,\ .\ .\ .\ B^j{}_n \rangle \qquad 17;$$

e) creating a set of difference vectors $\mathbf{C}^j$ each of n dimensions given by equation 18, the components of each difference vector $\mathbf{C}^j$ in the fourth collection being the difference between good part vector $\mathbf{A}$ and each defect vector $\mathbf{B}^j$:

$$\mathbf{C}^j = \mathbf{A} - \mathbf{B}^j \qquad 18;$$

f) identifying m components of vector $\mathbf{C}^j$ as provided by equation 19 having the largest magnitudes:

$$C^{j\prime}{}_i \in (C^{j\prime}{}_1,\ C^{j\prime}{}_2,\ .\ .\ .\ C^{j\prime}{}_m) \qquad 19;$$

wherein the m components are expressable as array $C^{j\prime}{}_i$, the largest magnitudes are identified independently for each vector $\mathbf{C}^j$, and each component of the $C^{j\prime}{}_i$ correspond to a value of the parameter p_i;

g) creating vector $\mathbf{D}^j$ of m dimensions as provided by equation 20 whose components are the n values in array $C^{j\prime}{}_i$

$$\mathbf{D}^j = \langle C^{j\prime}{}_1,\ C^{j\prime}{}_2,\ .\ .\ .\ C^{j\prime}{}_m \rangle$$
$$= \langle D^{j\prime}{}_1,\ D^{j\prime}{}_2,\ .\ .\ .\ D^{j\prime}{}_m \rangle \qquad 20;$$

h) normalizing vector $\mathbf{D}^j$ to form vector $\mathbf{E}^j$ as provided in equation 21:

$$\mathbf{E}^j = \mathbf{D}^j / |\mathbf{D}^j| \qquad 21;$$

i) determining array F_i of n numerical values as provided by equation 22 using the numerically quantifiable physical property that characterize a test part that may have an unknown defect

$$F_i \in (F_1,\ F_2,\ .\ .\ .\ F_n) \qquad 22;$$

j) creating vector $\mathbf{F}$ of n dimensions as provided by equation 23 whose components are the n values in array F_i

$$\mathbf{F} = \langle F_1, F_2, \ldots F_n \rangle \qquad 23;$$

k) forming a vector **G** as provided by equation 24 which is the difference between vector **A** and vector **F**:

$$\mathbf{G} = \mathbf{A} - \mathbf{F} \qquad 24;$$

l) identifying m components of vector **G** as provided by equation 25 which correspond to the same values for p_i as the m components selected in step g:

$$G'_i \in (G'_1, G'_2, \ldots G'_m) \qquad 25;$$

m) creating vector **H** as provided in equation 26 of dimension m having as components only the m components of step m:

$$\mathbf{H} = \langle G'_1, G'_2, \ldots G'_m \rangle$$
$$= \langle H_1, H_2, \ldots H_m \rangle \qquad 26;$$

n) optionally normalizing vector **H** to create vector **I** as provided in equation 27:

$$\mathbf{I} = \mathbf{H}/|\mathbf{H}| \qquad 27;$$ and

o) creating a set of dot products DP^i as provided in equation 28:

$$DP^i = \mathbf{E}^j \bullet \mathbf{I} \qquad 28;$$

wherein each dot product DP^i provides a number related to the probability that the test part that may have an unknown defect has the known defect in the second reference part with the largest dot product corresponds to the most likely defect in the product with an unknown defect.

15. The method of claim 14 wherein the numerically quantifiable physical property is a frequency spectrum which is the vibrational magnitude at one or more positions on the part as a function of frequency.

16. The method of claim 15 wherein

good part array A_i, defect array B_i, and array F_i are each ordered by n frequencies;

the n numerical values in good part array A_i are magnitudes from the frequency spectrum of the first reference part without a defect at each of the n frequencies;

the n numerical values in defect array B_i are magnitudes from the frequency spectrum of the second reference part with a known defect at each of the n frequencies; and

the n numerical values in array F_i are magnitudes from the frequency spectrum of a test part that may have an unknown defect at each of the n frequencies.

17. The method of claim 16 wherein the frequency spectrum of the first reference part, the second reference part, and the test part are determined by:

independently subjecting each of the first reference part, the second reference part, and the test part to energy that is sufficient to excite vibrational modes in each part;

independently measuring the magnitude of vibrations at one or more positions on each as a function of time to form a time domain spectra that is a plot of the magnitude of the vibrational energy as a function of time; and

independently creating a frequency domain spectra for each part by taking the Fourier transform of the time domain spectra.

18. The method of claim 17 wherein first reference part, the second reference part, and the test part are each a component of a vehicle powertrain and the subjecting a part to energy that is sufficient to excite vibrational modes in a part comprises:

operating the part in a manner as the part would be operated during operation of the powertrain.

19. The method of claim 18 further comprising:

calculating for each n frequencies a corresponding order;

reexpressing the frequency spectrum as a rotational order spectrum which is a plot of the vibration magnitude as a function of rotational order; wherein

the good part array A_i, defect array B_i, and array F_i are each ordered by the n rotational orders;

the n numerical values in good part array A_i are magnitudes from the rotational order spectrum of the first reference part without a defect at each of the n orders;

the n numerical values in defect array B_i are magnitudes from the rotational order spectrum of the second reference part with the known defect at each of the n orders; and

the n numerical values in array F_i are magnitudes from the order spectrum of the test part that may have an unknown defect at each of the n orders.

20. The method of claim 19 wherein the order is determined by dividing a frequency in the frequency spectrum by a reference frequency.

21. The method of claim 19 wherein the reference frequency is an input rotational frequency or output rotational frequency.

22. The method of claim 21 wherein the rotational frequency is determined of the rotation of a shaft within the part.

23. A method of characterizing defects in a part, the method comprising:

a) identifying a numerically quantifiable physical property that provides good part array A_i of n numerical values given by equation 1 that characterize a first reference part without a defect and defect array B_i of n values as provided by equation 2 that characterize a second reference part with a known defect:

$$A_i \in (A_1, A_2, \ldots A_n) \quad 1;$$

$$B_i \in (B_1, B_2, \ldots B_n) \quad 2;$$

wherein,

n is an integer, and

array A_i and array B_i are ordered by an independent parameter p_i that is associated with the values in array A_i and array B_i through the functional relationship $A_i = f_a(p_i)$ and $B_i = f_b(p_i)$;

b) creating good part vector **A** of n dimensions as provided by equation 3 whose components are the n numerical values in good part array A_i:

$$\mathbf{A} = \langle A_1, A_2, \ldots A_n \rangle \quad 3;$$

c) creating defect vector **B** of n dimensions as provided by equation 4 whose components are the n values in defect array B_i:

$$\mathbf{B} = \langle B_1, B_2, \ldots B_n \rangle \quad 4;$$

d) forming vector **E** by the method comprising;

1) creating difference vector **C** of n dimensions as provided by equation 5 which is the difference between good part vector **A** and defect vector **B**:

$$\mathbf{C} = \mathbf{A} - \mathbf{B} \quad 5;$$

2) identifying m components of vector **C** as provided by equation 6 having the largest magnitudes:

$C'_i \in (C'_1, C'_2, \ldots C'_m) 6;$

3) creating vector **D** of m dimensions as provided by equation 7 whose components are the n values in array C'_i

$\mathbf{D} = \langle C'_1, C'_2, \ldots C'_m \rangle$

$= \langle D_1, D_2, \ldots D_m \rangle$ 7; and

5) normalizing vector **D** to form vector **E** as provided in equation 9:

$\mathbf{E} = \mathbf{D}/|\mathbf{D}|$ 8;

e) determining array F_i of n numerical values as provided by equation 9 that characterize a test part that may have an unknown defect using the numerically quantifiable physical property:

$F_i \in (F_1, F_2, \ldots F_n)$ 9;

f) creating vector **F** of n dimensions as provided by equation 10 whose components are the n values in array F_i:

$\mathbf{F} = \langle F_1, F_2, \ldots F_n \rangle$ 10;

g) forming vector **I** by the method comprising:

1) creating vector **G** as provided by equation 11 which is the difference between vector **A** and vector **F**:

$\mathbf{G} = \mathbf{A} - \mathbf{F}$ 11;

2) identifying m components of vector **G** as provided by equation 12 which correspond to the same values for p_i as the m components selected in step d for vector **F**:

$G'_i \in (G'_1, G'_2, \ldots G'_m) 12;$

3) creating vector **H** as provided in equation 13 of dimension m having as components only the m components of step 2:

$$\mathbf{H} = \langle G'_1, G'_2, \ldots G'_m\rangle = \langle H_1, H_2, \ldots H_m\rangle \qquad 13;$$

4) normalizing vector **H** to create vector **I** as provided in equation 14:

$$\mathbf{I} = \mathbf{H}/|\mathbf{H}| \qquad 14;$$ and

h) forming dot product DP as provided in equation 15':

$$DP = \mathbf{E} \bullet \mathbf{I} \qquad 15';$$

wherein the dot product provides a number related to the probability that the test part that may have an unknown defect has the known defect in the second reference part.

24. A method of characterizing defects in a part, the method comprising:

a) identifying a numerically quantifiable physical property that provides good part array A_i of n numerical values given by equation 1 that characterize a first reference part without a defect and defect array B_i of n values as provided by equation 2 that characterize a second reference part with a known defect:

$$A_i \in (A_1, A_2, \ldots A_n) \qquad 1;$$

$$B_i \in (B_1, B_2, \ldots B_n) \qquad 2;$$

wherein,

n is an integer, and

array A_i and array B_i are ordered by an independent parameter p_i that is associated with the values in array A_i and array B_i through the functional relationship $A_i = f_a(p_i)$ and $B_i = f_b(p_i)$;

b) creating good part vector **A** of n dimensions as provided by equation 3 whose components are the n numerical values in good part array A_i:

$$\mathbf{A} = \langle A_1, A_2, \ldots A_n \rangle \qquad 3;$$

c) creating defect vector **B** of n dimensions as provided by equation 4 whose components are the n values in defect array B_i:

$$\mathbf{B} = \langle B_1, B_2, \ldots B_n \rangle \qquad 4;$$

e) determining array F_i of n numerical values as provided by equation 9 that characterize a test part that may have an unknown defect using the numerically quantifiable physical property:

$$F_i \in (F_1, F_2, \ldots F_n) \qquad 9;$$

f) creating vector **F** of n dimensions as provided by equation 10 whose components are the n values in array F_i:

$$\mathbf{F} = \langle F_1, F_2, \ldots F_n \rangle \qquad 10; \text{ and}$$

h) forming dot product DP as provided in equation 15:

$$DP = \mathbf{B} \bullet \mathbf{F} \qquad 15;$$

wherein the dot product provides a number related to the probability that the test part that may have an unknown defect has the known defect in the second reference part.

25. A method of characterizing defects in a part, the method comprising:

a) identifying a numerically quantifiable physical property in a part which is expressible as a measured dependant variable Y^d_i as a function of an independent variable X_i for a first reference part that has a known defect and wherein the measured dependant variable is determined at discrete intervals of the independent variable given by equation 31:

$$X_{i+1} = X_i + c \qquad 31;$$

wherein c is a constant;

b) providing a test pattern for the numerically quantifiable physical property such that dependant variable Y^n_i is expressed as a function of an independent variable X_i wherein values of Y^n_i are given at discrete intervals of the independent variable given by equation 32:

$$X'_{i+1} = X'_i + c \qquad 32;$$

wherein $X'_0 = X_0 + d$ and d is adjustable offset; and

c) forming the dot product sum DP given by equation 27:

$$DP = \Sigma Y^d_i Y^u_i \qquad 33;$$

wherein d is adjusted to provide the maximum value for P.

26. The method of claim 24 wherein the first reference part is a part with a known defect and the test pattern is determined by measuring the numerically quantifiable physical property to calculate dependant variable Y^n_i as a function of an independent variable X_i for a part that has an unknown defect.

27. The method of claim 24 wherein X_i and $'_i$ are restricted to adjacent values where Y^d_i and Y^u_i show variation.

28. The method of claim 24 wherein X_i and X'_i are time and Y^d_i and Y^u_i are the distance traveled by a cylinder in an internal combustion engine.